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FINAL REPORT ON PHASE I:

DEFINITION OF INTERCITY TRANSPORTATION COMPARISON FRAMEWORK

VOLUME I: SUMMARY

19 JULY 1978

PREPARED UNDER CONTRACT NAS2-9815

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA

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Silver Spring, Maryland 20910

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SYNOPSIS

This report presents a unified framework for comparing intercity passenger and freight transportation systems and illustrates the use of that framework with existing service and cost data for various freight systems. As the first phase of an intended two-phase effort, the emphasis here is on establishing comparative cost and service measures, the relationship between these measures, and a framework for comparison. Phase II is to deal with the construction of inputs, sensitivity analyses, the acquisition of data, and the actual conduct of the comparative analyses.

The key results of the first-phase investigation can be summarized as:

a. the formulation of a comparison framework utilizing composite measures, many of which are new, for intercity passenger and freight transportation systems

b. the articulation of a set of basic measures, forming the foundation for the computation of the composite measures

c. the construction of the parameter dependency diagram that explicitly inter-relates the composite and the basic measures

d. the provision of ground rules and methodology for development of the values of the basic measures

e. the formulation of an illustrative example of the use of the comparison framework for freight systems

f. the preliminary consideration of data base information requirements in order to support possible Phase II activities, and

g. an overview of the literature bearing upon and contributing to the overall problem of broad comparative analysis of intercity passenger and freight transportation systems.

The fundamental comparison framework is built around the computation of what ORI has called Composite Measures for alternative intercity passenger and freight transportation systems. These composite measures, many of which are new in the sense that they do not appear as such in literature examined to date, are calculated for each system under consideration, and then normalized and plotted to display how each of the systems compares with one another. These composite measures, listed in Table S.1, are formatted and then used, as appropriate and on an illustrative basis, to compare five intercity freight systems.

The composite measures, in turn, are developed from a set of variables called basic measures. There are fourteen basic measures, listed in Table S.2, categorized into the four attribute classes of:

- cost
- service/demand
- energy
- environmental impact.

The relationship between the composite measures and the basic measures is embodied in a parameter dependency diagram (PDD), a graphical representation of all measures showing explicitly the functional dependencies among all measures. The PDD incorporates twenty-three such relationships in displaying the manner in which the composite and basic measures are related. Therefore, if one starts with known or assumed values of the basic measures, the PDD and associated formulae provide for the computation of the composite measures, which are then used in the final framework for comparative analysis of intercity transportation systems. These concepts and relationships, including the illustrative freight system comparison, are presented in the first three sections of Volume II and in the main text of this volume.

TABLE S.1

COMPOSITE MEASURES

- TOTAL COST
- REVENUES
- PASSENGER MOBILITY INDEX (PMI)
- FREIGHT SERVICE INDEX (FSI)
- NET PROFIT (LOSS)
- COST PER PASSENGER-MILE
- COST PER TON-MILE
- RETURN ON INVESTMENT
- NET PRESENT VALUE
- PAYBACK PERIOD
- VIABILITY INDEX
- NORMALIZED PMI (NPMI)
- NORMALIZED FSI (NFSI)
- NPMI PER R&D COST
- NPMI PER TOTAL COST
- NFSI PER R&D COST
- NFSI PER TOTAL COST
- NPMI PER ENERGY USAGE
- NFSI PER ENERGY USAGE
- NPMI PER POLLUTANT EMISSION
- NFSI PER POLLUTANT EMISSION
- NPMI PER NOISE POPULATION
- NFSI PER NOISE POPULATION
- NPMI PER ENERGY USAGE PER R&D COST
- NPMI PER ENERGY USAGE PER TOTAL COST
- NFSI PER ENERGY USAGE PER R&D COST
- NFSI PER ENERGY USAGE PER TOTAL COST

TABLE S.2

ATTRIBUTES AND THEIR BASIC MEASURES

ATTRIBUTE	BASIC MEASURES
• COST	TOTAL R&D COST
	TOTAL INVESTMENT COST
	TOTAL OPERATIONS AND MAINTENANCE (O&M) COST
• SERVICE/DEMAND	PASSENGER DEMAND
	PASSENGER FARES
	FREIGHT DEMAND
	FREIGHT RATES
	DOOR-DOOR TRIP TIME/DOCK-DOCK TRIP TIME
	CAPACITY
	LOAD FACTOR
	SERVICE FREQUENCY
• ENERGY	ENERGY USAGE/PASSENGER-MILE
	ENERGY USAGE/TON-MILE
• ENVIRONMENTAL IMPACT	POLLUTION (by type)/YEAR
	POPULATION (affected by noise) WITHIN NEF 30

It is also recognized that a considerable amount of analysis may be required in order to develop values for the basic measures. Section IV of Volume II provides an overview of the process required to develop these basic measures. Subsequent chapters go into further detail regarding ground rules and relationships that are or could be important in constructing values for the basic measures.

Appendices, in Volume II, deal with worksheets for organizing basic measure information, data base considerations, a bibliography, which presents briefly the results of ORI's literature review, and a new air cargo concept (CLASS).

ACKNOWLEDGMENTS

Project leader for this study was Reynold Greenstone, Principal Scientist at ORI, Inc. Overall project direction was provided by Dr. Howard Eisner and Mr. Patrick Steen, ORI Executive Vice President and Vice President, respectively. Other ORI contributors to the study were Lawrence Kaplan, Joseph Lema, and C.W. Patten.

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SUMMARY PRESENTATION

1. OBJECTIVES

This report is part of an overall study whose objectives are to:

a. Develop a unified framework for the comparison of intercity passenger and freight transportation systems, and

b. Secure data on existing and possible future transportation system attributes so that comparisons may be made in future investigations.

2. SCOPE

It is intended that study comparisons be based upon several cost and service characteristics of different intercity systems and that a common set of variables be used so that all intercity systems may be considered, regardless of mode and current accounting and reporting procedures. The general approach is applicable to both passenger and freight service. An illustrative application is given in this report for a pure freight service.

This report deals only with Phase I of the projected overall study. (It is understood that a second phase is contemplated pending the outcome of this phase.) The scope of Phase I includes:

a. The establishment of categories of cost and service measures that will appropriately define the characteristics of all intercity transportation systems

b. The review of previous methods, as described in the literature, of comparing transportation systems

c. The definition of specific comparison variables, applicable to all modes, and the exploration of the functional relationships by which these variables are interdependent, and

d. The construction of a framework by which the set of variables may be employed for comparison of data from the individual systems.

In contrast with the above, the objectives of a future Phase II effort, as currently envisioned, include:

a. A detailed analysis of cost and service data required to translate, convert, or construct the proper inputs for use in the comparison framework

b. The testing of the sensitivity of the comparison framework to variations in the quality, range, and magnitude of the input data

c. The acquisition of required data from industry and government sources, and

d. The conduct of comparative analyses.

3. ORI'S APPROACH

Comparing alternative intercity passenger and freight transportation systems is not a simple process. There are a large number of variables of interest and, as each new variable is considered, additional analytic complexity is added. ORI has developed a comparison framework that can be used in a practical way by both analyst and decision maker. This necessitates compromises in complexity in order to preclude unwieldy or extremely time-consuming formalisms. Even with this overall approach, the comparison framework presented here is not simple nor can it be implemented effectively without the exercise of considerable judgment by potential users.

ORI has gone beyond conventional approaches and measures provided in the existing literature in this area. In particular, several new measures have been developed that subsume existing measures and tend to "boil down" the characterization of these systems to a smaller number of more universal measures. These are the Composite Measures (CM). The development of these new measures is a fundamental part of ORI's basic approach to this study and is discussed at length below.

4. UTILITY OF RESULTS

First and foremost, it is intended that the results presented here provide the basis for a consistent framework for comparative analyses. Second, the methodology is intended to be a tool to be used to set priorities for alternative technology investments for the future. It is primarily designed to be used by an analyst who will develop the intermediate and final output numbers and tabulations. The decision-maker will then be able to use the output comparisons, together with possibly subjective factors, constraints, and considerations to select among the alternatives that have been analyzed. The decision-maker will also be able to call for intermediate output results as well as sensitivity analyses with respect to selected parameters.

The methodology is not primarily focused, in its current form, on the matter of identifying research and development (R&D) needs for the future. However, given that a potential R&D need is presumed, and embodied in a system, that system can then be compared against alternative systems (including current or moderate expansions of existing systems) to obtain more rigorous measures of preference. For this reason, it is believed that the methodology can be effectively used to examine the efficacy of alternative R&D programs and the systems that they would support.

In several cases, as part of the overall methodology, ORI suggests alternative methods for carrying out the comparative analysis. These alternatives expand the scope of analysis which can be accomplished subject to the availability of resources (time, level of effort) that can be brought to bear by the potential user.

Finally, it is clear that there is a relationship between cost-benefit analysis and the subject of this study. ORI adopted the basic point of view that the focus of this effort was cost and service comparisons, without full consideration in particular of all possible benefits that could accrue from the selection of a particular system. Hence this study may be viewed as an essential subset of a full cost-benefit analysis of intercity transportation systems.

5. OVERVIEW OF MEASURES AND COMPARISON FRAMEWORK

There are a large number of variables that measure either the cost or service attributes of an intercity transportation system. Several hundred such variables can be readily identified and it is clearly not practical to compare systems with this number of variables. Many of these variables are interdependent, i.e., derivable from each other (e.g., cost per ton-mile depends upon total cost and number of tons delivered some total number of miles); many are defined at different system levels (total system vs. subsystem vs. element within a subsystem); and several are meaningful only when others are fixed (e.g., trip time is meaningful only when associated with a given trip distance).

As a means of sorting out these variables, ORI has identified three broad classes which are herein called input measures, basic measures, and composite measures. Figure 1 shows the approximate hierarchy: in general, input measures are used to calculate basic measures and basic measures (together with some input measures) are used to calculate composite measures. In addition, as a generality, final system comparisons are made primarily with the composite measures, secondarily with the basic measures, and rarely with the input measures. Emphasis is placed upon the composite and basic measures in order to construct the comparative framework called for in this investigation.

Basic Measures

The basic measures are grouped in categories, with each category representing a system attribute. These attributes and basic measures are listed in Table 1.

Composite Measures

The composite measures developed by ORI for final comparative analysis of intercity transportation systems are listed in Table 2.

The composite measures fit into three groups: those that represent the user's viewpoint, those that represent the Government's viewpoint, and those that represent the service provider's viewpoint. The user is concerned with the service he gets and its cost to him. The Government has the concern with R&D and total costs to achieve system realization and also with impacts on energy conservation and the environment that are not regarded as direct user or provider concerns. The provider wishes to make a sound investment with good returns for his capital.

Input Measures

Input measures are source data used to compute values of basic measures. As an example, the first basic measure listed in Table 1 is "total R&D cost." There has to be some basis for total R&D cost. Usually, this will be experiential data on other systems that in some way compare with the system now being proposed. These data on other systems or perhaps on R&D for comparable subsystems become the input data for the comparative analysis.

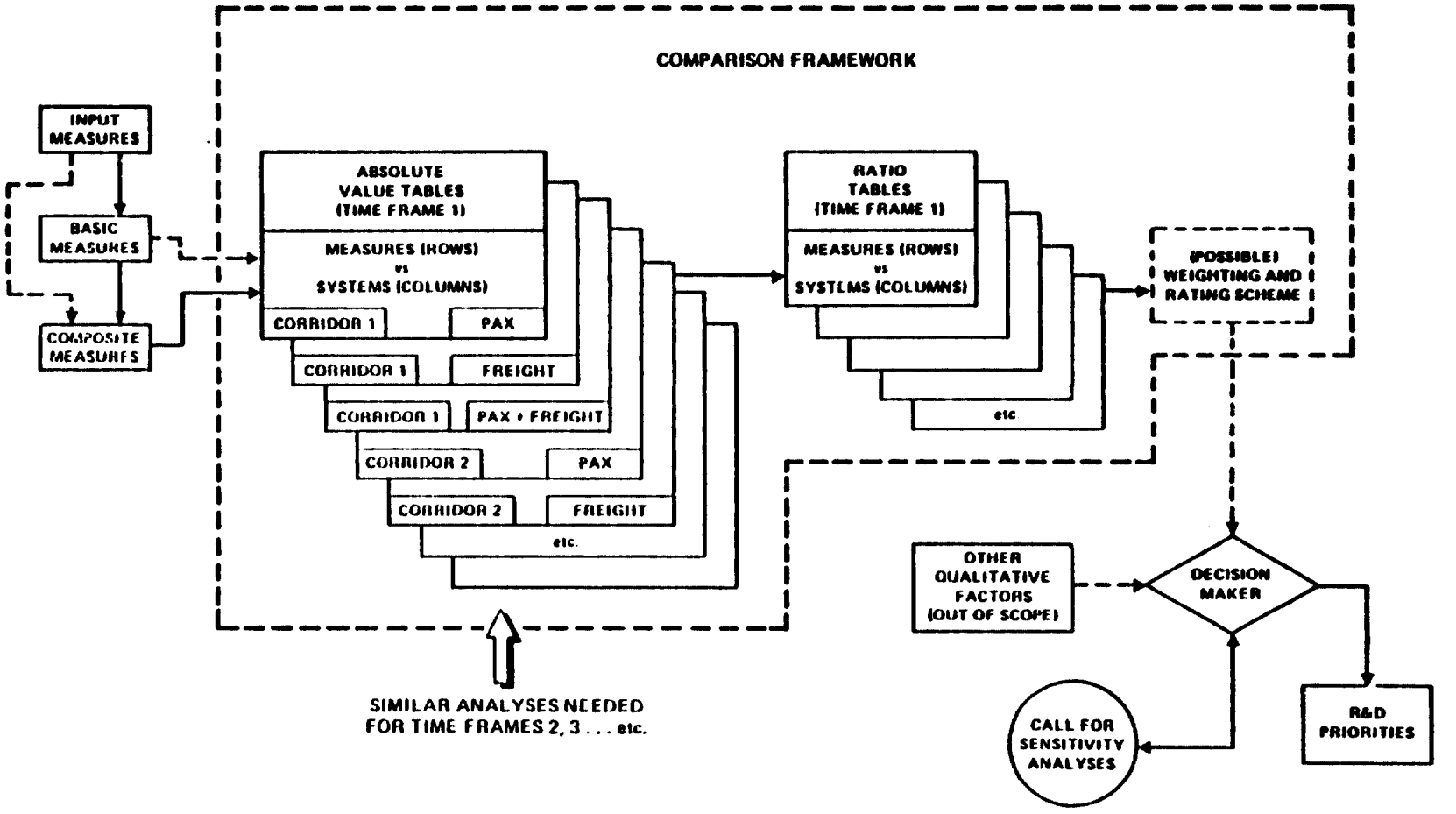

FIGURE 1. INPUT, BASIC AND COMPOSITE MEASURES AND COMPARISON FRAMEWORK

TABLE 1

ATTRIBUTES AND THEIR BASIC MEASURES

Attribute		Basic Measures	Units of Measurement
1. Cost	[1.1]	Total R&D Cost	Dollars
	[1.2]	Total Investment Cost	Dollars
	[1.3]	Total O&M Cost	Dollars
2. Service/ Demand	[2.1]	Passenger Demand	Pax-Miles/Year
	[2.2]	Passenger Fares	Dollars/Pax-Mile
	[2.3]	Freight Demand	Ton-Mile/Year
	[2.4]	Freight Rates	Dollars/Ton-Mile
	[2.5]	Door-Door Trip Time/ Dock-Dock Trip Time	Hours
	[2.6]	Capacity	Seats/Trip, Cubic Feet/Trip
	[2.7]	Load Factor	Fraction of Capacity That is Used
	[2.8]	Service Frequency	Trips/Year
3. Energy	[3.1]	Energy Usage/Passenger-Mile	BTU/Pax-Mile
	[3.2]	Energy Usage/Ton-Mile	BTU/Ton-Mile
4. Environmental Impact	[4.1]	Pollution (by type)/Year	Tons/Year
	[4.2]	Population Within NEF 30 (Noise Affected)	No. of People

TABLE 2
COMPOSITE MEASURES (CM's) DEVELOPED FOR COMPARATIVE ANALYSIS OF INTERCITY TRANSPORTATION SYSTEMS

CM 1. Total Cost

Total Cost = R&D Cost + Investment Cost + Operations & Maintenance (O&M) Cost.

CM 2. Revenues

Revenues = Pax Demand X Pax Fares + Freight Demand X Freight Fares.

CM 3a. Passenger Mobility Index

$$PMI = \frac{\left[1 - \exp\left(-f/f_o\right)\right]^{\alpha}\left[(1 - \text{Load Factor})\,(\text{Capacity})\right]^{\beta}}{[\text{Door-Door Trip Time}]^{\gamma}}$$

where f is service frequency, f_o is a normalizing factor, and α, β, and γ represent demand elasticities. (See discussion in Volume II regarding practical application of PMI.)

CM 3b. Freight Service Index

$$FSI = \frac{\left[1 - \exp\left(-f/f_o\right)\right]^{\alpha}\left[(1 - \text{Load Factor})(\text{Capacity})\right]^{\beta}}{[\text{Dock-Dock Trip Time}]^{\gamma}}$$

where f is service frequency, f_o is a normalizing factor, and α, β, and γ represent demand elasticities. In the illustrative numerical examples it was decided, for ease of calculation, to use the linear expression

$$FSI' = \frac{\text{Service Frequency x Capacity}}{\text{Dock-Dock Trip Time}}$$

wherein f_o, α, β, and γ are arbitrarily set to one, load factor is zero, and the exponential factor involving service frequency is replaced by service frequency alone. (See discussion in Volume II regarding practical application of FSI.)

TABLE 2 (CONT.)

CM 4. Net Profit (Loss)

Net Profit (Loss) = Revenues - Total Cost.

CM 5. Cost Per Passenger-Mile

$$\text{Cost/Pax-mile} = \frac{\text{Total Cost*}}{\text{Total Pax Miles}}$$

CM 6. Cost Per Ton-Mile

$$\text{Cost/Ton-Mile} = \frac{\text{Total Cost*}}{\text{Total Ton-Miles}}$$

CM 7. Profitability Measures

CM 7a. Return on Investment

$$\text{ROI} = \frac{\text{Net Profit (Loss)}}{\text{R\&D Costs + Investment Costs}}$$

CM 7b. Net Present Value

NPV = Present Value of Total Revenues - Present Value of Total Costs, where the present value of an amount that is expected to be received at a specified time in the future is that amount which, if invested today at a designated rate of return, would cumulate to the specified amount.

CM 7c. Payback Period

Payback Period = The year in which the cumulative net present values become non-negative and do not subsequently become negative.

CM 7d. Viability Index**

$$\text{Viability Index} = \frac{\text{Net Present Value}}{\text{Present Value of R\&D and Investment Cost}}$$

* Or share of total cost allocated to passengers or freight.

** See discussion of viability index in Section 7.7 of Volume II.

TABLE 2 (CONT.)

CM 8. Normalized PMI

$$NPMI = \frac{PMI}{\text{Cost/Pax-Mile}}$$

CM 9. Normalized FSI

$$NFSI = \frac{FSI}{\text{Cost/Ton-Mile}}$$

CM 10. NPMI per R&D Cost

$$\text{NPMI per R\&D Cost} = \frac{NPMI}{\text{R\&D Cost}}$$

CM 11. NPMI per Total Cost

$$\text{NPMI per Total Cost} = \frac{NPMI}{\text{Total Cost}}$$

CM 12. NFSI per R&D Cost

$$\text{NFSI per R\&D Cost} = \frac{NFSI}{\text{R\&D Cost}}$$

CM 13. NFSI per Total Cost

$$\text{NFSI per Total Cost} = \frac{NFSI}{\text{Total Cost}}$$

CM 14. NPMI per Energy Usage

$$\text{NPMI per Energy Usage} = \frac{NPMI}{\text{BTU/Pax-Mile}}$$

CM 15. NFSI per Energy Usage

$$\text{NFSI per Energy Usage} = \frac{NFSI}{\text{BTU/Ton-Mile}}$$

CM 16. NPMI per Pollutant Emission

$$\text{NPMI per Pollutant Emission} = \frac{NFSI}{\text{Pollutant Tons/Year}}$$

TABLE 2 (CONT.)

CM 17. NFSI per Pollutant Emission

$$\text{NFSI per Pollutant Emission} = \frac{\text{NFSI}}{\text{Pollutant Tons/Year}}$$

CM 18. NPMI per Noise Population

$$\text{NPMI per Noise Population} = \frac{\text{NPMI}}{\text{Population within NEF 30}}$$

CM 19. NFSI per Noise Population

$$\text{NFSI per Noise Population} = \frac{\text{NFSI}}{\text{Population within NEF 30}}$$

CM 20. NPMI per Energy Usage per R&D Cost

$$\text{NPMI per Energy Usage per R\&D Cost} = \frac{\text{NPMI per Energy Usage}}{\text{R\&D Cost}}$$

CM 21. NPMI per Energy Usage per Total Cost

$$\text{NPMI per Energy Usage per Total Cost} = \frac{\text{NPMI per Energy Usage}}{\text{Total Cost}}$$

CM 22. NFSI per Energy Usage per R&D Cost

$$\text{NFSI per Energy Usage per R\&D Cost} = \frac{\text{NFSI per Energy Usage}}{\text{R\&D Cost}}$$

CM 23. NFSI per Energy Usage per Total Cost

$$\text{NFSI per Energy Usage per Total Cost} = \frac{\text{NFSI per Energy Usage}}{\text{Total Cost}}$$

Comparison Framework

The comparison framework was shown diagrammatically in Figure 1. The composite measures are the primary inputs to a series of absolute value tables. These tables list the absolute values of the composite measures for each system under consideration. A table is produced for passenger, freight, and combined service and for each (geographic) corridor (or region) under investigation. For example, for three corridors, nine such tables would be developed.

The absolute value tables are then converted to ratio tables (see Figure 1). This is done by designating one of the systems as the "base case" system, which might represent an extension of the current system. The values in the ratio tables are then simply the ratios of the absolute values of the various systems compared to the base system. The quantities in the ratio tables are then dimensionless. (Examples of absolute value tables and ratio tables for freight service are given in Tables 3 and 4, respectively. See Subsection 10.)

An option then exists to carry the process one additional step. This step, also shown in Figure 1, is to use a "weighting and rating" scheme with the ratio table results to calculate "Figures of Merit" for each system. The weights correspond to the importance of each measure, established subjectively by the decision-maker or analyst. However, caution should be exercised in applying weightings and ratings to avoid inconsistencies. Some of the composite measures are, in fact, composites of composites. There is a danger in applying weightings to the "higher-order" composites that may belie the weightings applied to "lower-order" composites from which they are derived.

Displays of these results in forms other than tables can also be constructed to aid in the interpretation of results, but the fundamental data remain the same. In addition, the decision-maker can call for sensitivity analyses and/or selected values of other (basic and input) measures to assist in the decision-making process.

6. BASIC MEASURES

The basic measures defined by ORI are listed in Table 1. They are regarded as the fundamental measures by which any intercity transportation system may be characterized. They are also a possible basis of comparison between and among transportation systems and are commonly so used in other studies. ORI believes, however, that they suffer from the shortcoming of not being sufficiently inclusive of overall system characteristics. Combinations of these basic measures do lead to the more meaningful "composite measures" that are discussed later.

We note here what the basic measures are, and what they signify. Later in this section we show how they are combined to form the composite measures, which are of greater interest for application to the comparison framework. As shown in Table 1 the basic measures can be reasonably grouped into "attributes" and we will discuss them in those terms.

Cost Attribute

The basic cost attributes to be considered are total R&D costs, total investment costs, and total operating and maintenance (O&M) costs. R&D costs are all costs in the chain of research, development, and demonstration that lead to the design and implementation of a new system. R&D costs are incurred from the first conceptual design study of a new or improved system and may continue during the operation of the system as further improvements are sought. Investment costs are all costs of procurement including right-of-way, terminals, vehicles, control systems, etc. Operating costs are all costs concerned with actually moving people or goods through the system. "Total" as applied to R&D costs, etc., refers to the cumulative amount spent over a stated system lifetime.

Service/Demand Attribute

The service/demand attribute characterizes the service to be provided in terms of door-door trip time or dock-dock trip time, available capacity, and service frequency. The demand that is believed or assumed to be compatible with the service is characterized by the number of passenger-miles/year and the passenger fare in dollars per passenger-mile as well as the number of freight ton-miles per year and the freight rates in dollars per ton-mile. In a complete systems study the interactions among demand and fares or rates must be studied. In a broad-look study, compatible values of the basic measures of service and demand may have to be assumed. The selection of these values may be based on experience with comparable systems. Alternatively, the selection may be based on projections of new levels of commerce or wealth which may affect relative willingness to pay more for improved service.

Energy Attribute

As supplies of fossil fuels are seen to dwindle and prices go up, there is concern that energy usage by transportation systems be made more efficient. R&D is being applied to transportation systems to make them more energy efficient. Systems that are regarded as energy wasters will not get the go-ahead in years to come despite other service and cost advantages they may possess. Energy in BTU/ton-mile or BTU/passenger-mile has come to be known as energy intensity (EI)[1/].

Environmental Impact Attribute

The nation has been increasingly concerned with the need to minimize both biospheric pollution and noise associated with transportation systems. Gains in transportation service or efficiency must be measured in terms of additional pollutants that may be added to the air or to water systems and additional numbers of people exposed to annoying or harmful noise levels.

1/ Transportation Energy Conservation Data Book, Edition 2, ORNL-5320, Oak Ridge National Laboratory, October 1977.

7. COMPOSITE MEASURES

An important set of results of this study is the development of the composite measures. These measures are intended to aggregate and combine (primarily) the basic measures so that the systems being compared and evaluated can be characterized by a relatively small and therefore practical number of variables. As this aggregation and combining process occurs, it is recognized that information is "lost" as to the individual values of the basic measures. This is a by-product of the process; the analyst and/or decision-maker, however, can request the basic or input measure results if desired. An example is the submerging of frequency of departures and availability of seats per trip in the composite measure (PMI). This particular passenger-service measure and the comparable freight-service measure (FSI) are discussed further in Volume II, Section II.

Many of the composite measures are new in the sense that they do not appear as such in the existing literature. Therefore it will be necessary to work with such measures over a period of time to gain a full appreciation for their advantages and possible limitations. Such a process is envisioned for Phase II of this overall project. Within the scope of this effort, however, some illustrative examples are shown in order to see the numerical values for these measures for typical intercity systems. Section III of Volume II, in particular, runs through the comparative analysis process using data from various sources as well as typical values assumed for purposes of illustration.

The Parameter Dependency Diagram

The Parameter Dependency Diagram (PDD) has been adopted as a means of tracing backwards from the highest level composite measures, through the chain of functional relations, back to the basic measures whose values are needed to provide the initial system characterization. (See Figure 2.) Each composite measure appears as an output to the right of a rectangular box. The box represents the functional relationship, or model, which relates the inputs (other composite measures or basic measures) to the outputs. Thus the PDD ties

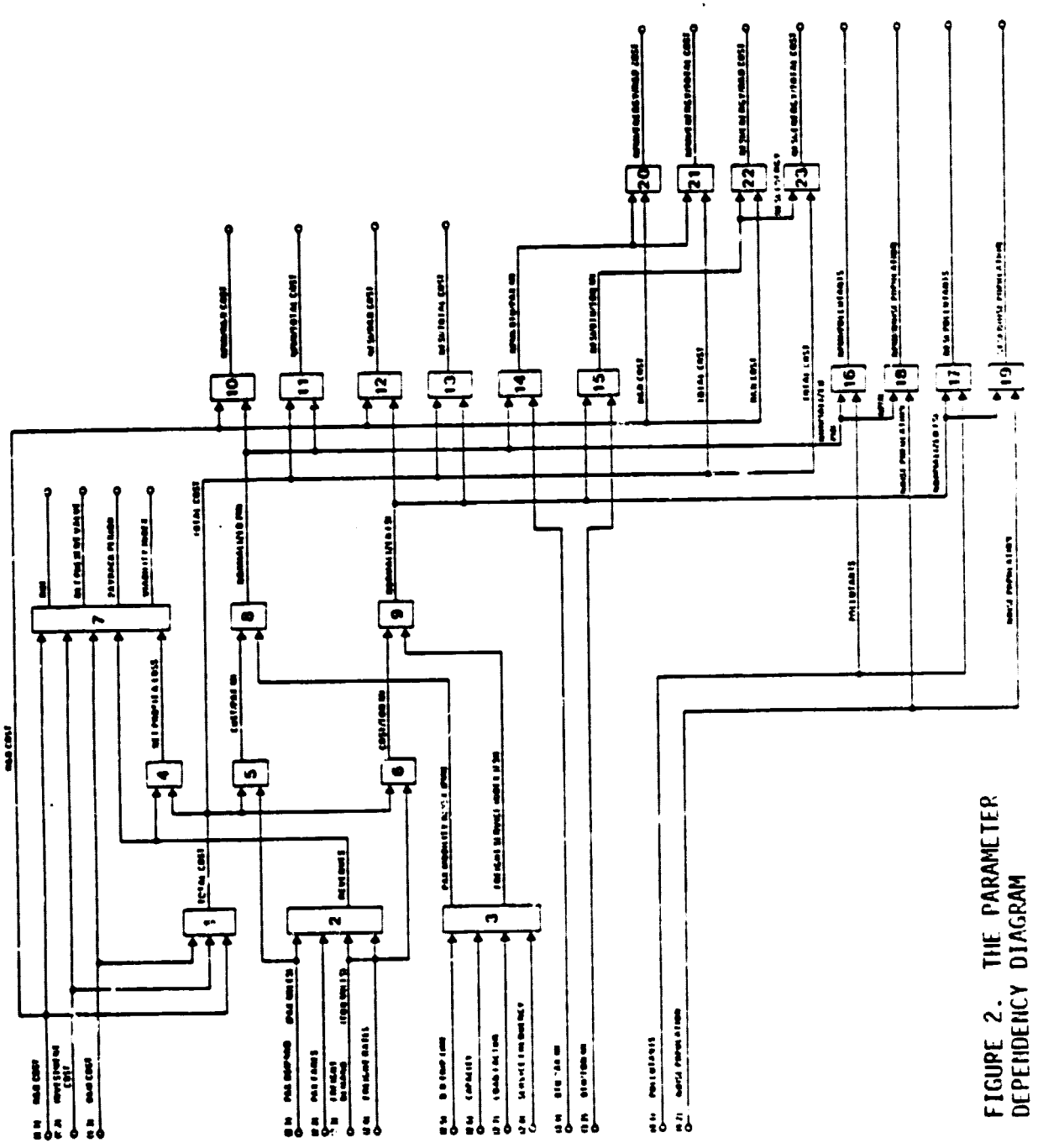

FIGURE 2. THE PARAMETER DEPENDENCY DIAGRAM

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parameters together and establishes the completeness of the representation of the transportation system characteristics.

As a general example, Figure 2 shows that "Normalized FSI" per R&D cost depends on R&D cost and on NFSI. The functional interrelationship in this instance is simply the ratio NFSI ÷ R&D cost. The nature of the composite measures is such that in almost every instance a new composite measure is the product or quotient of previously computed composite measures and basic measures.

As pointed out earlier, it is sometimes the case that a listing of basic measures as on the left side of Figure 2 suggests the formulation of new composite measures. For instance, if energy usage is an important consideration, R&D cost might be combined with BTU/ton-mile to arrive at another composite measure that was not shown in the Figure:

$$\frac{\text{BTU/ton-mile}}{\text{R\&D Cost}} \ .$$

Such a measure could be used to evaluate potential gains in energy efficiency versus the R&D costs to achieve those gains.

8. ILLUSTRATIVE VALUES OF COMPOSITE MEASURES

To show how the values of composite measures may be built up, we consider a hypothetical new freight transportation system proposed by TSC called TRAILS[2/] and follow along the Parameter Dependency Diagram as shown in Figure 2. For our example, we will develop numerical values of parameters for what TSC describes as the problem of shipping "domestic high-value containerizable freight" which characteristically "moves less than 1,000 miles and peaks at about 600 miles." The proposed new system should be capable of providing "line-haul link volumes of approximately 7 to 10 million net tons per year in both directions." The payload design density is 12-20 pounds/cu ft.

TRAILS is a conceptual high-speed freight-hauling system specified as "state-of-the-art in high-technology guideway." It involves individual fully automated, self-powered, steel-wheeled rail vehicles carrying containerized freight at running speeds of 120 mph between fully automated terminals. TRAILS uses electric power and runs on high-quality steel rails. Each TRAILS vehicle in the less-than-truckload (LTL) mode is loaded with 10- and 20-ft containers for several destinations and dispatched along a uniquely prescribed route.

To make the example specific, we choose a 600-mile link with 10-million tons capacity and 20 lb/cu ft payload density. We also select TSC data for less-than-truckload (LTL) shipments. This will be a <u>freight only</u> example. Hereafter, unless otherwise specified, it can be assumed that operational data referring to surface freight systems come from the TSC report.

<u>Box 1</u>

As inputs to Box 1 of the PDD we need R&D cost, Investment Cost, and O&M cost. The output is to be total cost. Section III of Volume II shows how a 30-year system cost for TRAILS of $15 billion (for the 600-mile link) was derived. Two hundred fifty million dollars was estimated as the cost of R&D for the TRAILS system.

2/ Advanced Freight Systems Study, Phase I, FY '77, Working Paper 16-77-2, Transportation Systems Center, September 30, 1977.

Sixty-six percent of TRAILS line-haul costs are given as and 34% are "operating costs." Applying these factors to the $15 billion total system costs we find investment costs = $9.9 billion and O&M costs = $5.1 billion. But we have already estimated $250 million for R&D costs. Assuming that these are part of investment costs, we adjust investment costs to $9.65 billion.

Thus, the inputs to Box 1 have these values:

[1.1] R&D Cost: $250 million

[1.2] Investment Cost (other than R&D): $9.65 billion

[1.3] O&M Cost: $5.1 billion

Box 2

Freight revenues depend on freight demand (ton-miles) and freight rates ($ /ton-mile). We know that the demand is 10 million tons x 600 miles = 6×10^9 ton-miles. The TSC report does not give freight rates. If we arbitrarily assume rates are 10 percent above costs, and use results computed in Volume II for costs, we obtain:

Freight cost = 6×10^9 ton-mile x $0.08/ton-mile $\approx$ $5 x 10^8.

Then annual freight revenue $\approx 1.10 \times \$5 \times 10^8 = \$5.5 \times 10^8$.

Box 3*

The freight service index FSI requires as inputs, in principle, dock-dock trip time, vehicle capacity, load factor, and service frequency. Using the simplified form for FSI given in Table 2 (see extended discussion of PMI and FSI in Section II of Volume II), we have

$$FSI' = \frac{\text{Service Frequency x Capacity}}{\text{Dock-Dock Trip Time}} .$$

* Entries referring to passenger service such as box 3a, box 5, box 8, etc., are omitted in this subsection, which is restricted to illustrative calculations for freight.

(A more appropriate version of FSI takes into account frequency saturation, load factor, and varying elasticities for the frequency, capacity, and trip time factors; in the remainder of this volume we will adhere to the simplified form, omitting the prime.) Volume II shows that service frequency x vehicle capacity = 10^9 cu ft/yr. Also dock-dock time is 31 hours. Then

$$FSI = \frac{10^9}{31} = 3.2 \times 10^7.$$

Box 4

Inputs to the net profit (loss)calculation include total (freight) revenues from Box 2 and total costs from Box 1. Assuming freight demand and rates remain constant over the 30-year time horizon, total revenues are $16.5 billion and total costs are $15 billion. Thus net profit equals $1.5 billion. On an annual basis this would amount to a net profit of approximately $50 million per year assuming straight-line depreciation of permanent capital over the operating period.

Box 6

Cost per ton-mile is determined, in principle, according to the PDD, from total cost and demand expressed in ton-miles. In fact, Volume II shows how, for our illustrative example, cost per ton-mile is determined from a breakout of handling costs and line-haul costs for the specific 600-mile link. The value determined for TRAILS is $0.08 per ton-mile.

Box 7

Return on investment is computed using annual net profit, the output of Box 4, and the sum of R&D [1.1] and investment costs [1.2]. An average ROI for the 30-year economic life is computed as follows:

$$ROI = \frac{\$5.0 \times 10^7}{\$2.5 \times 10^8 + \$9.65 \times 10^9} = 0.5 \text{ percent.}$$

The Net Present Value computation depends on operating revenues, obtained from Box 2, and the following costs:

[1.1] R&D Cost

[1.2] Investment Cost

[1.3] O&M Cost.

The time horizon for the net present value analysis is 40 years. It is assumed that in the first 5 years total R&D costs are spent in equal increments of $\$5 \times 10^7$ per year. In years 4 through 13 capital investment costs are incurred at the rate of $\$9.65 \times 10^8$ per year. Total O&M costs are assumed to be incurred equally over the 30-year operating period on the average of $\$1.7 \times 10^8$ per year. Annual operating revenues of $\$5.5 \times 10^8$ are also earned from years 11 to 40.

The present value of the annual operating revenues received in years 11 to 40 assuming the OMB-prescribed discount rate of 10 percent is:

$$\$5.5 \times 10^8 \times 3.634 = \$2.00 \times 10^9.$$

The present values of the various cost streams are as follows:

$$\text{R\&D Cost} = \$5 \times 10^7 \times 3.791 = \$1.90 \times 10^8$$

$$\text{Investment Cost} = \$9.65 \times 10^8 \times 4.616 = \$4.45 \times 10^9$$

$$\text{O\&M Cost} = \$1.7 \times 10^8 \times 3.634 = \$6.18 \times 10^8.$$

The difference between the present value of the operating revenue and the sum of the present values of the R&D, investment, and operating costs is the net present value:

$$\text{Net Present Value} = \$2.00 \times 10^9 - \$5.26 \times 10^9 = -\$3.26 \times 10^9 .$$

The payback period for this system is beyond its useful life since the discounted revenues never exceed the discounted costs.

The viability index depends on the net present value and the discounted initial investment:

$$\text{Viability Index}^* = \frac{-3.26 \times 10^9}{4.64 \times 10^9} = -0.71 .$$

Box 9

Normalized FSI requires knowledge of FSI (Box 3) and cost per ton-mile (Box 6). Then

$$\text{NFSI} = \frac{3.2 \times 10^7}{0.08} = 4 \times 10^8 .$$

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* See Section 7.7 of Volume II.

Box 9

Normalized FSI requires knowledge of FSI (Box 3) and cost per ton-mile (Box 6). Then

$$NFSI = \frac{3.2 \times 10^7}{0.08} = 4 \times 10^8 .$$

Box 12

Normalized FSI per R&D cost requires knowledge of NFSI (Box 9) and R&D cost (basic measure [1.1]). Then

$$\frac{NFSI}{R\&D\ Cost} = \frac{4 \times 10^8}{\$2.5 \times 10^8} = 1.6 .$$

Box 13

Normalized FSI per Total Cost requires knowledge of NFSI (Box 9) and Total Cost (Box 1). Then

$$\frac{NFSI}{Total\ Cost} = \frac{4 \times 10^8}{15 \times 10^9} = 0.027 .$$

Box 15

Normalized FSI per energy usage requires knowledge of NFSI (Box 9) and energy usage (basic measure [3.2]). We establish in Volume II that energy usage by TRAILS is approximately 2100 BTU/ton-mile. Then

$$NFSI/Energy\ Usage = \frac{4 \times 10^8}{2100} = 1.9 \times 10^5 .$$

Box 17

Normalized FSI per pollutant emission rate requires knowledge of NFSI (Box 9) and pollutant emission rate (basic measure [4.1]). We did not establish a CO emission rate for TRAILS because TRAILS is an electric system drawing roadside power. Any emission would be due to the stationary electric power generating system.

Box 19

Normalized FSI per population affected by noise requires knowledge of FSI (Box 9) and the population within the NEF 30 contour (basic measure [4.2]). Since neither the NEF 30 contour nor the population distribution along the TRAILS right-of-way are readily available, we substitute the measure "noise level-area" for which we have computed the value 910 dB-sq mi. Then

$$\frac{\text{NFSI}}{\text{Noise Level-Area}} = \frac{4 \times 10^8}{910} = 4.4 \times 10^5 .$$

Box 22

Normalized FSI per energy usage per R&D cost requires knowledge of NFSI per energy usage (Box 15) and of R&D cost (basic measure [1.1]). Then

$$\frac{\text{NFSI}}{\text{BTU/Ton-Mi} \times \text{R\&D Cost}} = \frac{1.9 \times 10^5}{2.5 \times 10^8} = 7.6 \times 10^{-4}.$$

Box 23

Normalized FSI per energy usage per total cost requires knowledge of NFSI per energy usage (Box 15) and of total cost (Box 1). Then

$$\frac{\text{NFSI}}{\text{BTU/Ton-Mi} \times \text{Total Cost}} = \frac{1.9 \times 10^5}{15 \times 10^9} = 1.3 \times 10^{-5} .$$

9. COMPARISON FRAMEWORK

In preceding paragraphs we have shown composite measures that can be formulated to describe numerically the key characteristics of a freight or passenger system. The absolute values of the composite measures of a transportation system are not of intrinsic value by themselves but rather in comparisons between and among systems.

The service that can be provided, the cost of providing it, and the possible financial, energy, or environmental impacts are functions of the particular setting in which a transportation system is to be employed. Thus, ORI recommends that a set of site-specific scenarios be employed for the comparison, if the proposed systems are intended for national use. Typical sites that have been considered in other transportation studies are the Northeast Corridor (Richmond to Boston or some segment of the Corridor such as Washington to Boston), the Pacific Corridor (San Diego to Sacramento), etc.

The detailed sequence of steps to be followed in developing the comparison framework appears in Section IV of Volume II. Broadly, the steps are those that include selecting geographic sites and time frames for comparison, selecting the systems to be compared, performing those studies that enable the basic measures and composite measures to be evaluated, and then presenting the comparison in a form that can be effectively used by the decision maker (see Figure 3).

The comparison presentations should include:

1) For each geographic site and time frame, <u>absolute</u> values of basic and composite measures for each system being compared.

2) For each geographic site and time frame, <u>ratios</u> of values of basic and composite measures for each system being compared. One system is taken to be the base comparison case and then ratios are taken of values of measures for other systems to values for the base case. (This same procedure can be used to compare a developmental version of a current system as it might evolve in some future year

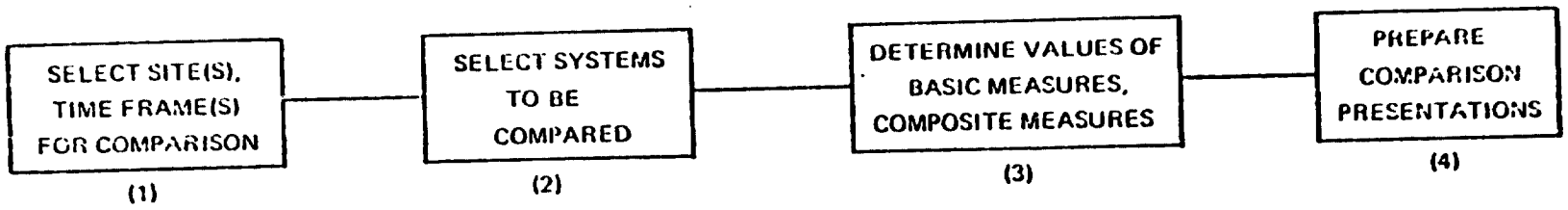

FIGURE 3. OUTLINE SKETCH OF STEPS IN DEVELOPING COMPARISON FRAMEWORK (SEE FIGURE 4.1 OF VOLUME II FOR GREATER DETAIL.)

with the current system, essentially unaltered,
but also providing service in the future year.)

10. SUMMARY COMPARISON OF FIVE SAMPLE SYSTEMS

The ORI methodology has been applied to the comparison of five freight systems in Volume II. The 40' Motor Carrier System, serving a 600-mile link, served as the comparison base. The additional systems were two surface systems, TRAILS (the high-speed automated rail system) and the Trailer on Flat Car (TOFC), and two air systems, the Narrow Body (NB) IGLOO and the Wide Body Lower Hold (WBLH).

Table 3 presents in summary fashion the values of the composite measures and some of the basic measures that were developed in Volume II. Any row of the table is for a particular measure. Each column is for one of the five systems being compared. Remembering that composite measures have been defined so that large values are desirable, one can scan any row of the table for composite measures and appreciate the relative system rankings. Remembering again that the numerical values assigned to the various quantities are in many instances more suggestive than valid, one can use the table to select systems that appear to be the best or the worst according to the various composite measures. Thus, for instance, TRAILS never dominates and, when R&D cost is taken into account, TRAILS seems poorest. On a pure service basis (FSI) the air mode dominates, but when service is normalized by cost (NFSI), the air mode loses its apparent advantage.

The Trailer on Flat Car (TOFC) system can be seen to have the advantage when energy intensity is taken into account as in the computation of NFSI/EI, NFSI/EI/R&D cost, and NFSI/EI/Total Cost.

The 40' Motor Carrier has the advantage in terms of NFSI , NFSI/R&D cost, NFSI/Total Cost, and NFSI/Noise Level Area.

A method of revealing the relative advantages and disadvantages of the various systems is to represent their composite measure values relative to the value of a particular system. With this in mind all comparative measure values are normalized to that for 40' Motor Carrier. When this is done the relative numbers are as shown in Table 4 and in Figure 4. Recall that composite measures

TABLE 3

COMPOSITE MEASURES SUMMARY TABLE: 600 MILE TRIP - 10 MTONS SYSTEM CAPACITY REQUIREMENTS (10^9 cu ft capacity, assumes 2.6 tons shipped by surfaced mode, LTL)

ROW	MEASURE	SYSTEM				
		40' MOTOR CARRIER[1] (LTL), U-U Terminal	TRAILS[1]	TOFC[1] (Dedicated 35-car train)	NB IGLOO AIR FREIGHT[3] (Container)	WBLH[3]
1.	FSI	2.5×10^7	3.2×10^7	1.7×10^7	3.7×10^7	3.7×10^7
2.	Cost/ton -mile	$ 0.06	$ 0.08	$ 0.05	$ 0.22	$ 0.13
3.	NFSI	4.2×10^8	4.0×10^8	3.4×10^8	1.7×10^8	2.8×10^8
4.	EI: (BTU/ton-mile)[2]	2000	2100	700	12,900	9000
5.	NFSI/EI	2.1×10^5	1.9×10^5	4.9×10^5	1.3×10^4	3.1×10^4
6.	Total R&D Cost	10^5	$ 2.5 \times 10^8$	10^5	10^5	10^5
7.	NFSI/R&D Cost	4.2×10^3	1.6	3.4×10^3	1.7×10^3	2.8×10^3
8.	Total System Cost	11×10^9	15×10^9	$ 9 \times 10^9$	41×10^9	24×10^9
9.	NFSI/Total Cost	3.8×10^{-2}	2.7×10^{-2}	3.9×10^{-2}	4.1×10^{-3}	1.2×10^{-2}
10.	NFSI/EI/ R&D Cost	2.1	7.6×10^{-4}	4.9	0.13	0.31
11.	NFSI/EI/ Total Cost	1.9×10^{-5}	1.3×10^{-5}	5.4×10^{-5}	3.2×10^{-7}	1.3×10^{-6}
12.	Tons Per Year[4] (CO) Pollutant	2000		950		
13.	NFSI/ Pollutant Rate	2.1×10^5		3.6×10^5		
14.	Noise-Level-Area (sq. mile)	900	910	890		
15.	NFSI/Noise-Level-Area	4.7×10^5	4.4×10^5	3.8×10^5		
16.	ROI (%)	1.1	0.5	1.0	1.0	1.0
17.	NPV ($)	-1.60×10^9	-3.26×10^9	-2.50×10^9	-5.90×10^9	-3.37×10^9
18.	Viability Index	-0.73	-0.71	-0.73	-0.75	-0.74

[1] TSC's Advanced Freight Systems Study is principal source of operations data for surface systems.

[2] Transportation Energy Conservation (TEC) Data Book is source for energy data.

[3] Trends and Choices is principal source of operations data for air systems.

[4] Compilation of Air Pollutant Emission Factors (CAPE) is source for pollutant data when combined with TEC.

TABLE 4

RATIOS OF COMPOSITE MEASURES
USING 40' MOTOR CARRIER AS THE BASE

MEASURE	SYSTEM				
	40' MOTOR CARRIER	TRAILS	TOFC	NB IGLOO	WBLH
FSI	1	1.3	0.7	1.5	1.5
NFSI	1	1.0	0.8	0.4	0.7
NFSI/EI	1	0.9	2.3	0.1	0.2
NFSI/R&D Cost	1	4×10^{-4}	0.8	0.4	0.7
NFSI/Total Cost	1	0.7	1.0	0.1	0.3
NFSI/EI/R&D Cost	1	3.6×10^{-4}	2.3	0.06	0.15
NFSI/EI/Total Cost	1	0.7	2.8	0.02	0.07
NFSI/Pollutant Rate	1	-	1.7	-	-
NFSI/Noise-level Area	1	0.9	0.8	-	-
ROI	1	0.5	0.9	0.9	0.9
NPV*	1	2.0	1.6	3.7	2.1
Viability Index**	1	1	1	1	1

*All computed values of NPV were negative. Thus smallest values of these ratios are "best."

**All computed values of viability index were negative and within 3% of each other

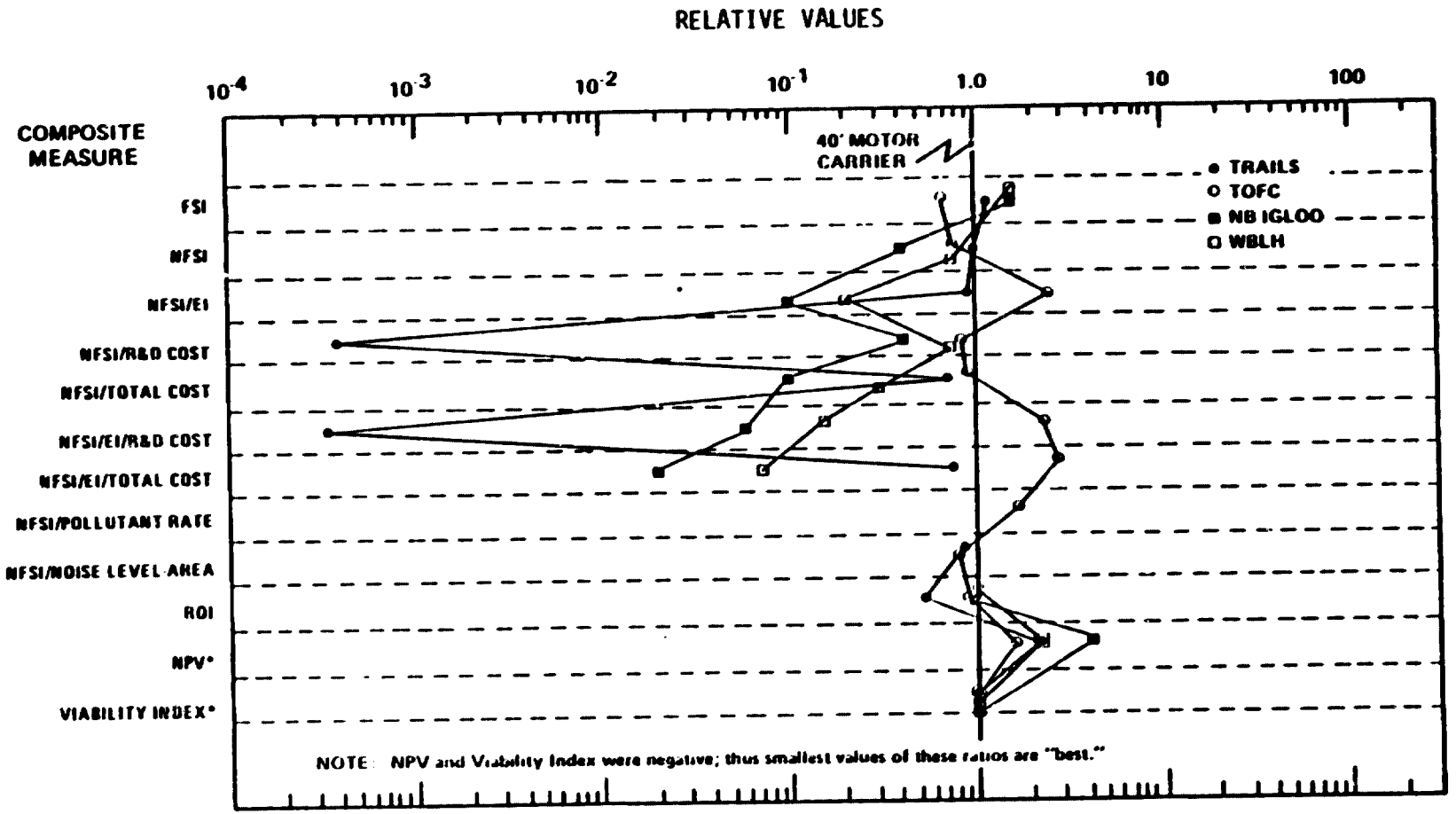

FIGURE 4. RELATIVE VALUES OF COMPARATIVE MEASURES NORMALIZED TO 40' MOTOR CARRIER

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have been defined so that large values are better than small. When ratios are taken, numbers larger than one indicate that the comparison system is superior to the base system. Ratios less than one indicate that the opposite is true.

Figure 4 quickly conveys the message (sharp peaks to the right) that when R&D costs are considered, as in NFSI/R&D cost and NFSI/EI/R&D cost, all other systems are preferable to TRAILS. (This result may be an artifact of the choice of $250 million R&D cost for TRAILS versus $100,000 for the other systems. Still, even if the R&D costs were adjusted by several orders of magnitude, there would be a tendency for TRAILS to have a low relative value.) Purely on a service basis (FSI), TRAILS and the air systems dominate the rail and highway systems. This is because of their greater speed.

If energy usage is a key factor, NFSI/EI and NFSI/EI/Total Cost both indicate that all the surface systems tend to be preferable by more than an order of magnitude to the air systems.

When financial measures are considered, it can be seen that none of the systems that were analyzed looks very promising. (It is best to look at Table 3 because the ratios presented in Table 4 and Figure 4 are not appropriate for negative values.)

The return on investment (ROI) for each of the five systems is less than one percent, well below interest rates or the ten-percent discount rate used in the net-present-value (NPV) calculations. This result must be viewed in the light of the arbitrariness of the method employed in this study in allocating investment and O&M costs and setting freight rates. (Freight rates were assumed arbitrarily to be set at ten percent above costs.)

The negative values of NPV are consistent with the low ROI. If ROI is less than ten percent, and ten percent is the assumed discount rate in the NPV analysis, it can be expected that the NPV will turn out to be negative. In this sense, of insufficient return on investment, the systems analyzed are not viable.

The apparent insensitivity of viability index to type of system is a consequence of an unrealistic assumption discussed in Volume II that all systems charged rates that were ten percent above cost.

11. SUMMARY OF COMPARATIVE ANALYSIS PROCESS

The procedure we propose for the overall comparative analysis process has been shown in Figure 1. Through the use of the Parameter Dependency Diagram we establish the appropriate composite measures. Then, for each type of transportation service, in each geographical service context, we establish absolute values of the composite performance measures and show the results in absolute value tables. Selecting one system as the base, we establish ratios of performance measures and show the results in ratio tables. An optional step is to apply formal weighting schemes to the results given in the absolute value and ratio tables. The results of this work are shown to the decisionmaker who may call for sensitivity analyses to guide him in setting R&D priorities.

We have shown in this volume how to obtain values of both the basic and composite measures for only one system, TRAILS. In Volume II we show how to extend the comparison by establishing absolute and relative values for measures relating to four additional freight service systems.

The analysis would normally proceed from the abstract concept of performance in a 600-mile-link to a realistic setting such as a corridor or region and then to as many corridors or regions as is feasible or desirable. We have not carried our example beyond the single, abstract, service context of the 600-mile link, but clearly the same method will be applicable to any number of corridors or regions. Time-frame analysis was not treated explicitly in the illustrative example but should be treated in a full-scale study. It would imply further sets of absolute value and ratio tables for the time frames of interest.

As was stated above, Volume II shows how to apply the comparison framework to five alternative freight systems, including one highway, two rail, and two air systems. There is a discussion in Volume II of the significance to be attached to the relative values of the various composite measures for each of the systems. Volume II also gives the generalized procedures to be followed in obtaining values of the basic measures and examples of data sources and functional relations that may be used to conduct comparison studies.